SPECIFICATION

SILENCER FOR PASSAGE

TECHNICAL FIELD

[0001] The present invention relates to a silencer for a passage to be mounted in the passage through which gas or liquid flows for reducing noises which are propagated through the passage.

BACKGROUND OF THE INVENTION

[0002] A passage which allows gas or liquid to pass therethrough propagates not only fluid but also noises and hence, conventionally, there has been known a passage which mounts a silencer for reducing the propagation of such noises thereon.

[0003] As a typical example, in an industrial plant or a building which generates large noises, there has been a drawback that these noises easily propagate through a duct. To reduce such noises, in general, there has been used a duct silencer which silences the noises by absorbing acoustic energy of the noises using a sound absorbing member such as glass wool.

[0004] As one of duct silencers which uses the sound absorbing member, Fig. 23 shows a splitter-type duct silencer X1 which divides the inside of a duct D finely in the vertical direction or in the lateral direction using partition walls 20 made of a metal plate or the like, and mounts a sound absorbing member 21 on surfaces of the partition walls 20 or inner wall surfaces of the duct D, while Fig. 24 shows a cell-type duct silencer X2 which finely divides the inside of the duct D into cells finer than cells of the splitter-type duct silencer X1.

[0005] In these duct silencers X1 and X2, an arrangement area of the sound absorbing member 21 is increased by partitioning the inside of the duct D with the partition wall 20 thus increasing a noise attenuation quantity. However, the above-mentioned sound absorbing member 21 made of glass wool or the

like exhibits the poor silencing capacity at a low frequency band and hence, it is difficult to prevent the propagation of the noises at the low frequency band.

[0006] Accordingly, the inventor of the present invention has proposed a duct silencer which is disclosed in Japanese Patent Laid-open No. 2003-216159 (patent document 1), wherein by arranging a soft acoustic section soft in acoustics where a sound pressure on an inner wall surface becomes substantially zero is arranged on the inner wall surface, the propagation of the noises in the low frequency band can be prevented. The soft acoustic section is configured such that a plurality of acoustic pipes having a length from an open end to a closed end thereof disposed on inner wall surface of the duct equal to 1/4 of a wavelength of a sound wave of noises (hereinafter referred to as 1/4 wavelength acoustic pipes) is arranged in parallel to each other over a length more than approximately a half wave length of the sound wave of noises in the longitudinal direction of the duct.

[0007] In the conventional duct silencer which uses the 1/4 wavelength acoustic pipes, it is necessary to continuously arrange the soft acoustic section over more than approximately a half wave length of the sound wave of noises on the inner wall surface of the duct. Accordingly, there exists a possibility that in a predetermined region where the soft acoustic section is formed, it is difficult to provide other constitution to the duct. Accordingly, the constitution of the duct is restricted or a region where the duct silencer can be mounted is limited.

[0008] Further, in the duct silencer which uses the 1/4 wavelength acoustic pipes, a silencing effect is difficult to achieve unless an open width of the duct is equal to or less than a half wavelength of the sound wave of noises. Accordingly, when the open width of the duct exceeds the half wavelength of the sound wave of noises, it is necessary to divide the inside of the duct by partition walls as in the case of the cell-type

or the splitter-type duct silencer. In this case, when the 1/4 wavelength acoustic pipes are arranged on the partition walls, the partition walls become thick thus lowering an opening rate with respect to a cross-sectional area of the duct.

[0009] For example, in the cell-type duct silencer X2 shown in Fig. 24, when the 1/4 wavelength acoustic pipes are arranged in place of the sound absorbing member 21, as shown in Fig. 25(a), assuming that an opening width "t" of one cell is $\lambda/2$ of a maximum value (λ being a wavelength of the sound wave), the acoustic pipes having a length of $\lambda/4$ are arranged along four peripheral surfaces of the cell. Accordingly, the total cross-sectional area becomes $2\lambda \times 2\lambda = 4\lambda^2$, wherein an area which allows an air flow to pass therethrough becomes $\lambda/2 \times \lambda/2 \times 4 = \lambda^2$. That is, the opening ratio becomes 1/4.

[0010] Further, even when the 1/4 wavelength acoustic pipes are arranged on only two opposing surfaces around the periphery of the cell as shown in Fig. 25(b), for example, the opening ratio becomes 1/2.

[0011] In this manner, when the 1/4 wavelength acoustic pipes are applied to the partition walls which divide the inside of the duct, a more than half of the cross-sectional area of the duct is occupied by the structural body. Accordingly, the air permeability of the duct is lowered thus giving rise to a possibility that it is difficult to use the 1/4 wavelength acoustic pipes in an actual practice.

Patent document 1: Japanese Patent Publication No. 2003-216159

DISCLOSURE OF THE INVENTION

[0012] Here, in the present invention according to in claim 1, on an inner wall surface of a passage, a soft acoustic section soft in acoustics where a sound pressure at an inner wall surface of the passage is approximately zero and a non-soft acoustic section where a sound pressure at the inner wall surface of the passage is not zero are alternately arranged over

more than approximately a half wavelength of a sound wave to be silenced in a longitudinal direction of the passage.

[0013] Further, according to the present invention described in claim 2, the passage is divided by partition walls such that an opening width becomes a half wave length or less of the sound wave to be silenced. On both side surfaces of the partition wall, the soft acoustic section soft in acoustics where the sound pressure at the inner wall surface of the passage is approximately zero and the non-soft acoustic section where the sound pressure at the inner wall surface of the passage is not zero are alternately arranged over more than approximately a half wavelength of the sound wave to be silenced in the longitudinal direction of the passage.

[0014] Further, according to the present invention described in claim 3, in the present invention described in claim 1 or claim 2, the soft acoustic section is formed of an acoustic pipe having a length thereof from an open end of the pipe disposed on a wall surface to a closed end equal to 1/4 of the wavelength of the sound wave to be silenced.

[0015] Further, according to the present invention described in claim 4, in the present invention described in claim 3, the acoustic pipe has the open end thereof covered with a film.

[0016] Further, according to the present invention described in claim 5, in the present invention described in claim 3 or claim 4, the soft acoustic section is formed by arranging an open end of the acoustic pipe on one wall surface of the partition wall, and the non-soft acoustic section is formed by arranging a closed end of the acoustic pipe on another wall surface.

[0017] Further, according to the present invention described in claim 6, in the present invention described in any one of claims 1 to 5, the non-soft acoustic section is formed of a sound absorbing member which reduces a sound pressure.

[0018] Further, according to the present invention described in claim 7, a first silencing means is mounted on one pair of inner

wall surfaces out of two pairs of oppositely facing inner wall surfaces of the passage having a rectangular cross section, and a second silencing means which has silencing property different from silencing property of the first silencing means is mounted on another pair of the inner wall surfaces. The first silencing means is configured such that a soft acoustic section soft in acoustics where the sound pressure at the inner wall surface of the passage is approximately zero and a non-soft acoustic section where the sound pressure at the inner wall surface of the passage is not zero are alternately arranged over more than approximately a half wavelength or more of the sound wave to be silenced in the longitudinal direction of the passage.

[0019] Further, according to the present invention described in claim 8, the passage is divided by the partition walls so as to form a plurality of miniaturized passages having a rectangular cross section in the passage such that an open width becomes a half wavelength or less of the sound wave to be silenced. A first silencing means is mounted on one pair of inner wall surfaces out of two pairs of oppositely facing inner wall surfaces of the miniaturized passage, and a second silencing means which has silencing property different from silencing property of the first silencing means is mounted on another pair of the inner wall surfaces. The first silencing means is configured such that a soft acoustic section soft in acoustics where the sound pressure at the inner wall surface of the passage is approximately zero and a non-soft acoustic section where the sound pressure at the inner wall surface of the passage is not zero are alternately arranged over more than approximately a half wavelength or more of the sound wave to be silenced in the longitudinal direction of the passage.

[0020] Further, according to the present invention described in claim 9, in the present invention described in claim 7 or claim 8, the soft acoustic section is formed of an acoustic pipe having a length from an open end of the pipe disposed on a wall

surface to a closed end equal to 1/4 of a wavelength of the sound wave to be silenced.

[0021] Further, according to the present invention described in claim 10, in the present invention described in claim 9, the acoustic pipe has the open end thereof covered with a film.

[0022] Further, according to the present invention described in claim 11, in the present invention described in claim 9 or claim 10, the soft acoustic section is formed by arranging an open end of the acoustic pipe on one wall surface of the partition wall, and the non-soft acoustic section is formed by arranging a closed end of the acoustic pipe on another wall surface.

[0023] Further, according to the present invention described in claim 12, in the present invention described in any one of claims 7 to 11, the second silencing means is configured such that a sound absorbing section which reduces a sound pressure of the sound wave to be silenced is formed on the inner wall surface.

BRIEF EXPLANATION OF THE DRAWINGS

[0024] Fig. 1 is an explanatory view of a measuring device which measures a silencing capacity of a duct silencer;

Fig. 2 is a perspective view showing an acoustic pipe arrangement body of the duct silencer which becomes an object to be tested;

Fig. 3 is a perspective view showing an acoustic pipe arrangement body of the duct silencer which becomes an object to be tested;

Fig. 4 is a perspective view showing an acoustic pipe arrangement body of the duct silencer which becomes an object to be tested;

Fig. 5 is an explanatory view of the boundary surface structure of the duct silencer which becomes an object to be tested;

Fig. 6 is a graph showing a result of measurement of the silencing capacity of the duct silencer;

Fig. 7 is a graph showing a result of measurement of the silencing capacity of the duct silencer;

Fig. 8 is a graph showing a result of measurement of the silencing capacity of the duct silencer;

Fig. 9 is an explanatory view showing a use state of one embodiment of the duct silencer in cross section;

Fig. 10 is an explanatory view of a cross-sectional shape taken along a line I-I in Fig. 1;

Fig. 11 is an explanatory view showing the arrangement of soft acoustic sections and non-soft acoustic sections in a region II in Fig. 1;

Fig. 12 is a perspective view showing one embodiment of the duct silencer;

Fig. 13 is a perspective view showing the duct silencer of another embodiment;

Fig. 14 is an explanatory view of the boundary surface structure of the duct silencer which becomes an object to be tested;

Fig. 15 is an explanatory view of the boundary surface structure of the duct silencer which becomes an object to be tested;

Fig. 16 is an explanatory view of a measuring device which measures a silencing capacity of a duct silencer;

Fig. 17 is a graph showing a result of measurement of the silencing capacity of the duct silencer;

Fig. 18 is a graph showing a result of measurement of the silencing capacity of the duct silencer;

Fig. 19 is an explanatory view showing a use state of another embodiment of the duct silencer in cross section;

Fig. 20 is an explanatory view of a cross-sectional shape taken along a line III-III in Fig. 19;

Fig. 21 is an explanatory view showing the arrangement of soft acoustic sections and non-soft acoustic sections in a region IV in Fig. 19;

Fig. 22 is a graph showing a result of an experiment which confirms advantageous effects when a film is mounted on an open portion of an acoustic pipe;

Fig. 23 is an explanatory view of a conventional splitter-type duct silencer;

Fig. 24 is an explanatory view of a conventional cell-type duct silencer; and

Fig. 25 are explanatory views showing a state in which a 1/4 wavelength acoustic pipe is arranged in the conventional cell-type duct silencer, wherein (a) is an explanatory view showing a state in which the 1/4 wavelength acoustic pipe is arranged on four peripheral surfaces of the cell, and (b) is an explanatory view in which the 1/4 wavelength acoustic pipe is arranged on only two opposing peripheral surfaces of the cell.

BEST MODE FOR CARRYING OUT THE INVENTION

[0025] A silencer for a passage according to the present invention is used in a state that the silencer for a passage is mounted on a duct which performs intake and discharge of air and a ventilation hole which performs ventilation. Here, in the embodiments described hereinafter, as a typical embodiment of the silencer for a passage according to the present invention, a duct silencer which is mounted on a duct is explained. However, it is needless to say that the present invention is not limited to the duct silencer and is applicable to a silencer in general which is mounted on a passage for a fluid such as a gas or a liquid.

[0026] A duct silencer which constitutes one embodiment of the silencer for a passage according to the present invention includes a soft acoustic section soft in acoustics where a sound pressure on an inner wall surface becomes substantially zero and

a non-soft acoustic section where the sound pressure at the inner wall surface of the passage is not zero which are alternately arranged over more than approximately a half wavelength of a sound wave to be silenced in the length direction of the passage.

[0027] That is, the above-mentioned duct silencer can be mounted on the inside or on the outside of the duct, and when the duct silencer is attached on the inside of the duct, a new duct inner wall consisting of the soft acoustic section and the non-soft acoustic section is formed at a position at which the new inner wall of the duct projects toward the central side of the duct than an original inner wall level of the duct, while in case the duct silencer is attached on the outside of the duct, a new duct inner wall consisting of the soft acoustic section and the non-soft acoustic section is formed on the same level as the original inner wall of the duct.

[0028] Here, it is preferable that the constitution which is formed of the soft acoustic section and the non-soft acoustic section is provided to at least a pair of oppositely facing inner wall surfaces of the duct.

[0029] Further, the duct silencer is configured such that, in so-called the cell-type or the splitter-type duct silencer which, when the open width of the duct is larger than the wavelength of the sound wave which becomes an object to be silenced (hereinafter, referred to as an object sound wave), divides the duct using partition walls so as to make the open rate to be a half wavelength or less of the object sound wave, on both side wall surfaces of the partition wall, the soft acoustic section soft in acoustic where the sound pressure at the wall surface is approximately zero and the non-soft acoustic section where the sound pressure at the wall surface is not zero are alternately arranged over more than approximately the half wavelength of the sound wave to be silenced in the length direction of the duct.

[0030] Also by mounting the duct silencer at the partition wall, a new wall surface is formed by the soft acoustic section and the non-soft acoustic section of the duct silencer.

[0031] That is, when the duct silencer is mounted on the duct, a predetermined region of the inner wall surface of the duct or the wall surface of a partition wall is formed of the soft acoustic section and the non-soft acoustic section of the duct silencer.

[0032] The above-mentioned non-soft acoustic section includes a sound absorbing acoustic section which has a function of reducing a sound pressure, which is not zero, by using a sound absorbing member such as a metallic fiber represented by glass wool, rock-wool and aluminum fiber, a foamed aluminum, a ceramic absorbing material or the like, a rigid acoustic section rigid in acoustics which is made of a rigid body such as a metal plate in the same manner as a duct and has no sound pressure reducing function and the like. In the non-soft acoustic section, a silencing function (a noise reduction function) is not a prerequisite. For example, an original wall surface of the duct may be used as the non-soft acoustic section.

[0033] Further, in the duct silencer, this non-soft acoustic section and the soft acoustic section which has a silencing function are alternately arranged on the inner wall surface of the duct or on both-side wall surfaces of the partition wall. That is, on the inner wall surface of the duct or on both-side wall surfaces of the partition wall, the soft acoustic section and the non-soft acoustic section are arranged in parallel to each other in a checkered pattern or in a striped pattern.

[0034] In this manner, on the inner wall surface of the duct or on both-side wall surfaces of the partition wall, not only the soft acoustic section but also non-soft acoustic section are arranged and hence, a region which is occupied by the soft acoustic section which is to be constituted such that a sound pressure thereof is zero can be reduced thus increasing a region

of the duct on which the duct silencer of the present invention can be mounted.

[0035] Further, in the inside of the duct, not to mention that the sound wave to be silenced can be silenced by the silencing function of the soft acoustic section, by making use of the non-soft acoustic section which is alternately arranged with the soft acoustic section as either the sound absorbing acoustic section or the rigid acoustic section as mentioned previously, the duct silencer can be used for multi purposes.

[0036] Particularly, by assuming the above-mentioned non-soft acoustic section as a sound absorbing acoustic section and by forming the non-soft acoustic section using a sound absorbing member such as a fiber material which can decrease the sound pressure, it is possible not only to silence a sound wave in a predetermined frequency band which is an object sound wave in the soft acoustic section, but also to silence a sound wave in a different predetermined band in the non-acoustic section, the frequency band in which the sound wave can be silenced by the silencer can be expanded so as to enhance the silencing effect of the silencer.

[0037] Further, as mentioned above, by forming the wall surface per se of the duct into the non-acoustic section, the use of new constitution can be obviated and hence, the silencer becomes light-weighted.

[0038] On the other hand, the soft acoustic section, to be more specific, can be constituted of an acoustic pipe (a 1/4 wavelength acoustic pipe) having a length thereof from an open end of the pipe disposed on a wall surface to a closed end set to 1/4 of a wavelength of a sound wave which becomes the object to be silenced. When the soft acoustic section is constituted of such an acoustic pipe, by changing a length of the acoustic pipe corresponding to a wavelength of a sound to be silenced, it is possible to silence sounds having various wavelengths.

[0039] Further, the non-soft acoustic section may be formed between the acoustic pipes which constitute the soft acoustic section. Accordingly, even when the soft acoustic section is occupied with the acoustic pipes, the non-soft acoustic section may be provided as open spaces and hence, it is possible to use these open spaces for other purposes. For example, when the duct silencer is disposed outside the duct, the duct silencer is mounted on a periphery of the duct in a projecting manner. However, by making use of the non-soft acoustic section as the open space, even in a narrow space such as an attic space or the inside of a wall where many other wires, pipes and the like are arranged, it is possible to broaden the possibility that the duct silencer of the present invention can be installed.

[0040] Further, by mounting a film having a small resistance in acoustics and as an extremely large resistance as a fluid on the opening portion of the acoustic pipe, it is possible to constitute the soft acoustic section using acoustic pipes which are shorter than the above-mentioned 1/4 wavelength. Accordingly, by covering the opening portion of the acoustic pipe with a film made of plastic or the like, it is possible to easily realize the miniaturization of the duct silencer, the easy mounting of the duct silencer and the reduction of weight of the duct silencer.

[0041] In this manner, when the opening part of the acoustic pipes are closed with the film, it is possible to previously prevent a generation of noises caused by an air flowing in the inside of the duct collide to the open end of the acoustic pipes so that the flow in the duct is disturbed.

[0042] Further, when the above-mentioned acoustic pipes are applied to the partition walls which divide the inside of the duct into a plurality of small ducts, it is possible to form the soft acoustic section by arranging the open end of the acoustic pipe on one wall surface of the partitions and to form the non-soft acoustic section by arranging the closed end of the

acoustic pipe on another wall surface of the partitions. Due to such a constitution, it is sufficient that the thickness of the partition wall is set to a length of one acoustic pipe and hence, the partition wall may be formed thin. Accordingly, even when the duct is divided by the partition walls, an area where the partition walls occupies in cross section of the duct can be decreased as much as possible thus silencing the object sound wave without lowering an air fluidity in the inside of the duct.

[0043] To arrange the soft acoustic section and the non-soft acoustic section alternately as described above, even when the soft acoustic section is not continuously provided over more than approximately the half wavelength of the object sound wave in the length direction of the duct, the object sound wave must be silenced at the soft acoustic sections which are arranged at a predetermined intervals within the above-mention half wavelength. However, this evidence is certificated by a comparative test that a silencing capacity of a duct silencer in which the soft acoustic section is continuously provided and a silencing capacity of a duct silencer in which the soft acoustic section and the non-soft acoustic section are alternately provided are compared with each other. Hereinafter, the comparative test is explained in conjunction with the drawings.

[0044] In Fig. 1, a measuring device M which measures a silencing capacity of the duct silencer is shown.

[0045] The measuring device M includes an acrylic-resin-made duct D which has a square cross-sectional shape of 10cm(10cm and a length of 2m. A terminal end portion of the duct end D is formed into a non-reflective end on which a sound absorbing wedge M1 is mounted, a speaker M2 which constitutes a sound source is mounted on a start end portion of the duct D opposite to the non-reflective end, and a microphone M3 which collects the sound outputted from the speaker M2 is mounted in front of the above-mentioned sound absorbing wedge M1 which is arranged closer to the non-reflective end side than the speaker M2.

[0046] Further, between the speaker M2 and the microphone M3, that is, on a center portion of the duct D which is arranged closer to the non-reflective end side than the speaker M2, a duct silencer to be tested is mounted and hence, it may be measured how much a sound outputted from the speaker M2 is silenced by passing through the duct silencer.

[0047] Fig. 2 to Fig. 4 shows an acoustic pipe array which constitutes the duct silencer A1 to A9 which have been tested in this time.

[0048] The acoustic pipe array is constituted to set in array the plural acoustic pipes in a perpendicular direction and/or a horizontal direction and includes, a first acoustic pipe array 6 in which the acoustic pipes 1 (a 1/4 wavelength acoustic pipe) made of aluminum which has a sectional shape of 5cm by 5cm and a length of 1/4 of the wavelength of 1000Hz sound wave are arranged in parallel in 2 rows and 10 columns as shown in Fig. 2 and is mounted in a state that a surface b (hereinafter, referred to as a boundary surface) which is boundary with a inner space of a duct D, that is, the inner wall surface of the duct D becomes a opening portions of the first acoustic pipe 1, a second acoustic pipe array 7 in which the openings of the acoustic pipes of even number rows or odd number rows out of the first acoustic array 6 are all closed by a rigid body 2 such as a aluminum plate as shown in Fig. 3, a third acoustic pipe array 8 in which glass wool of a sound absorbing member 3 is adhered on to the rigid body 2 which closes the openings of the acoustic pipe 1 of the second acoustic pipe array 7, a fourth acoustic pipe array 9 in which the openings of the acoustic pipe 1 of the first acoustic pipe array 6 are alternately closed by the aluminum plates in a checkered pattern as shown in Fig. 4 and, at the same time, glass wool of a sound absorbing member 3 is adhered on to the rigid body.

[0049] That is, the above-mentioned first to fourth acoustic pipe array 6, 7, 8, 9 are designed so as to set a frequency to

be silenced 1000 Hz, particularly, the first acoustic pipe array 6 has the soft acoustic section over all the boundary surface b which has the length of half wavelength of the frequency to be silenced or more, the second and third acoustic pipe array 7, 8 has the soft acoustic section and the non-soft acoustic section which is arranged in a striped pattern over all the boundary surface b which has the length of half wavelength of the frequency to be silenced or more, the fourth acoustic pipe array 9 has the soft acoustic section and the non-soft acoustic section which is arranged in a checkered pattern over all the boundary surface b which has the length of half wavelength of the frequency to be silenced or more. And in this comparative test, by combining a plurality of the above-mentioned first to fourth acoustic pipe array 6, 7, 8, 9, the 9 types of the silencer (the first to fourth silencer A1 to A9) are formed.

[0050] Fig. 5 shows a boundary surface structure of the acoustic pipe array in the respective silencer A1 to A9. As shown in the drawings, the first silencer to the sixth silencer, A1 to A6 consists of two acoustic pipe arrays mounted on the left wall and the right wall of the duct D, while the seventh silencer to the ninth silencer, A7 to A9 consists of four acoustic pipe arrays mounted on the left wall, the right wall, the top wall and the bottom wall of the duct D. In the drawings, a "matted triangle" indicates a start end side (the side on which a speaker M2 is mounted) of the duct D.

[0051] In Fig. 6 to Fig. 8, a result of the measured silencing ability of the first silencer to the ninth silencer, A1 to A9 is shown. Here, in Fig. 6 to Fig. 8, on an axis of ordinates, a sound volume (dB) of the sound wave is taken as an attenuation quantity from the reference value, wherein the silencers A1 to A9 are not mounted thus allowing the whole inner wall surface of the duct D to be a rigid body 2, in which by setting the sound volume (dB) of the sound wave collected by a microphone M3 as

the reference value, the sound volume of the sound wave is collected when the respective silencers A1 to A9 are mounted. Further, an axis of abscissas is a frequency axis which shows the band between 300 Hz to 3000 Hz.

[0052] Fig. 6 shows a measurement result of the silencers A2, A3 and A4 in the second and the third acoustic pipe arrays 7 and 8 in which the boundary surface b is arranged in the form of strips are mounted on an opposing pair of surfaces of the duct D.

[0053] A solid line, as shown in Fig. 5, indicates a result of measuring the first silencer A1 as a comparison example, wherein the first acoustic pipe array 6 whose boundary surface b is totally the soft acoustic section 4 is mounted on a pair of opposing surfaces of the duct D and exhibits a sound reducing effect equal to or more than 40 dB in a range approximately between 850 Hz to 1200 Hz centering on 1000 Hz.

[0054] An alternate long and short dash line, as shown in Fig. 5, indicates a result of measuring the second silencer A2, wherein the boundary surface structure of an opposing pair of the second acoustic pipe array 7 coincide with each other such that the soft acoustic section 4 to the soft acoustic section 4 and the non-soft acoustic section 5 to the non-soft acoustic section 5. Although the sound reducing effect of the silencer A2 is approximately the same as the sound reducing effect of the first silencer A1, the frequency band which indicates the sound reducing effect is shifted toward the low frequency in the second silencer A2.

[0055] An alternate long and double-short dash line, as shown in Fig. 5, indicates a result of measuring the third silencer A3, wherein another acoustic pipe array opposing to the second acoustic pipe array 7 is the first acoustic pipe array 6 and the upper limit of the frequency band in which the sound reducing effect is seen is a little higher than the upper limit of the frequency band of the second silencer A2.

[0056] A dashed line, as shown in Fig. 5, indicates a result of measuring the fourth silencer A4, wherein the boundary surface structures of the opposing pair of the third acoustic pipe array 8 coincide to each other and the sound reducing effect before and after 1000 Hz which is a determined frequency to be silenced does not show any changes whereas a large attenuation (approximately 15 dB) is obtained at a higher frequency band. This is an effect of the sound absorbing member 3.

[0057] Fig. 7 shows the result of measuring the silencers A5 and A6, wherein the fourth acoustic pipe array 9 in which the boundary surface b includes the soft acoustic section 4 and the non-soft acoustic section 5 extracted in a checkered pattern with each other is mounted on one opposing pair of the surface of the duct D.

[0058] In Fig. 7, as a comparison example, the results of measuring the first silencer A1 and the fourth silencer A4 which are explained in the above-mentioned Fig. 6 is shown. The solid line indicates the result of measuring the first silencer A1 and the alternate long and double-short dash line indicates the result of measuring the fourth silencer A4.

[0059] The dashed line, as shown in Fig. 5, indicates the result of measuring the fifth silencer A5, wherein the boundary surface structures of the opposing pair of the fourth acoustic pipe array 9 coincide to each other, and the upper limit of the frequency band in which the sound reducing effect is seen is approximately the same as in the above-mentioned fourth silencer A4, however, the lower limit of the frequency band exhibits a little higher in the fifth silencer A5. Further, in case of the fifth silencer A5, although it is not an obvious sound reducing effect, in the frequency band equal to 1000 Hz or less which is a frequency band to be silenced, a certain degree of sound reducing effect can be seen.

[0060] The alternate long and short dash line indicates the result of measuring the sixth silencer A6, wherein different

from the fifth silencer A5, an opposing pair of the boundary surface structure of the third acoustic pipe array 8 includes the soft acoustic section 4 and the non-soft acoustic section 5 which are inconsistent to each other. In comparing the sixth silencer A6 to the fifth silencer A5, although the frequency band in which the sound reducing effect appears is approximately the same as in the fifth silencer A5, by eliminating before and after 1000 Hz which is the frequency to be silenced, as a whole, the sound reducing effect of the sixth silencer A6 is lower than the sound reducing effect of the fifth silencer A5.

[0061] Fig. 8 shows results of measurement of the silencers A8, A9 which mount fourth acoustic pipe array 9 which have boundary surfaces b formed into a checkered pattern consisting of the soft acoustic section 4 and the non-soft acoustic section 5 on whole four surfaces of the duct D.

[0062] As shown in Fig. 5, a solid line indicates, as a comparison example, a result of a measurement of a seventh silencer A7 which mounts the first acoustic array 6 in which whole boundary surface b is formed of the soft acoustic section 4 on all four surfaces of the duct D. The result shows that the seventh silencer A7 exhibits the substantially same sound reducing effect of equal to or more than 40 dB around 1000 Hz as the above-mention first silencer A1.

[0063] As shown in Fig. 5, a dotted line indicates a result of a measurement of the eighth silencer A8 in which the boundary surface structures of the two facing fourth acoustic arrays 9 agree to each other in the respective two pairs of oppositely facing fourth acoustic arrays 9. Here, when the result the measurement of the eighth silencer A8 is compared with the result of the measurement of the seventh silencer A7, a frequency range in which the sound reducing effect of equal to or more than 40 dB around 1000 Hz is viewed is narrowed. Further, although a silencing effect appears even in a frequency

range of 1000 Hz to 2000 Hz, the silencing effect is not so large, that is, an approximately 10 dB.

[0064] A chain line indicates a result of a measurement of the ninth silencer A9 in which the boundary surface structures of the two facing fourth acoustic arrays 9, different from the eighth silencer A8, do not agree to each other in the respective two pairs of oppositely facing fourth acoustic arrays 9. The result shows that also a large sound reducing effect appears around 1000 Hz which is a frequency of the object to be silenced, and the result also shows that a large sound reducing effect of 30 dB is obtained in the vicinity of 2000 Hz.

[0065] According to the results of the measurement shown in Fig. 6 to 8, even when the soft acoustic section 4 is not arranged over more than approximately a half wavelength or more of the object sound wave (here, 1000 Hz) in the length direction of the duct, by the non-soft acoustic section 5 and the soft acoustic section 4 which are alternately arranged with each other between the half wavelengths, it is possible to obtain a silence function equal to a silence function which is obtained by arranging the soft acoustic section 4 continuously.

[0066] Further, when the non-soft acoustic section 5 is constituted of a sound absorptive acoustic section which is formed of the sound absorbing member 3, in addition to the silence function of the soft acoustic section 4, a silence function due to the sound absorptive acoustic section is operated and hence, it is possible to broaden a frequency band in which the silencing effect appears.

[0067] Next, an embodiment of a duct silencer is explained in detail in conjunction with drawings. Here, in the following explanation, the embodiment is explained when the duct silencer is applied to a cell type duct silencer.

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explanation, the embodiment is explained when the duct silencer is applied to a cell type duct silencer.

[0068] Fig. 9 is an explanatory view in a sectional direction showing an embodiment of the duct silencer in a state of operation, Fig. 10 is a cross-sectional explanatory view of Fig. 1 as viewed from a line I-I, and Fig. 11 is an explanatory view of Fig. 1 showing an arrangement of the soft acoustic section 4 and the non-soft acoustic section 5 in a region II.

[0069] As shown in the drawings, the duct silencer A10 of this embodiment is mounted on an exhaust port D1 portion of a rectangular-shaped duct D as viewed in a sectional direction which constitutes a cooling tower for air conditioning, and includes acoustic pipe arrays for a duct 10 which is respectively arranged on a pair of opposed inner wall surfaces of the duct D, acoustic pipe arrays for partition walls which constitute three longitudinal partition walls which partition the duct in a longitudinal direction and three lateral partition wall 12 which partition the duct in a lateral direction. In the drawing, numeral 13 indicates a blower.

[0070] The acoustic pipe arrays for duct walls 10 are formed in a plate shape by arranging 1/4 wavelength acoustic pipes 1 made of aluminum having a rectangular cross-sectional shape with one closed end whereas another opened end in parallel along the duct wall in a perpendicular direction and a horizontal direction and, at the same time, the openings of the acoustic pipe 1 are alternately closed by rigid bodies 2 such as aluminum plates and sound absorbing members 3 made of glass wool are adhered on to the rigid bodies 2 in a state that the closed end or the opened end is not continuously arranged between two adjacent 1/4 wavelength acoustic pipes 1. As shown in Fig. 11, boundary surfaces b which is boundary with an inner space of a duct D, that is, the inner wall surfaces of the duct D are constituted of the openings (soft acoustic section 4) of the acoustic pipes 1 and the sound absorbing members 3 (non-soft acoustic section

5) which are adhered on to the rigid bodies 2 in a checkered pattern.

[0071] On the other hand, the acoustic pipe array for a partition wall 11 is formed in a plate shape by alternately arranging 1/4 wavelength acoustic pipes 1 made of aluminum having a rectangular cross-sectional shape with one closed end whereas another opened end in parallel in a perpendicular direction and a horizontal direction in a state that the closed end or the opened end is not continuously arranged between two adjacent 1/4 wavelength acoustic pipes 1, and in this embodiment, the acoustic pipe array for a partition wall 11 is constitutes a longitudinal partition wall as it is.

[0072] That is, the acoustic pipe array for a partition wall 11 is constituted in a state that front-back both surfaces constitute boundary surfaces b which is boundary with an inner space of a duct D, and the acoustic pipe 1 which the opening portion thereof is arranged on the one boundary surface b is constituted in a state that the closed portion thereof is arranged on another boundary surface b. Further, the sound absorbing members 3 made of glass wool is adhered on to the above-mentioned closed portion, and in the boundary surface b, b of the front-back both sides of the acoustic pipe array for a partition wall 11, as shown in Fig. 11, the opening portion of the acoustic pipe 1 and the sound absorbing members 3 (the non-soft acoustic section 5) of the closed portion are formed in a checkered pattern.

[0073] Here, the above-mentioned acoustic pipe array for a duct wall 10 and acoustic pipe array for a partition wall 11 are arranged over the length of half wavelength or more of the sound wave to be silenced in a longitudinal direction.

[0074] Further, the lateral partition wall 12 includes the rigid body 2 such as an aluminum plate, and is partitioned by the lateral partition 12 and the acoustic pipe array for a partition wall 11 which constitutes the above-mentioned

longitudinal partition wall in a state that the opening width t of the duct D is a dimension of the half wavelength or less.

[0075] In this manner, in the duct silencer A10 according to this embodiment, since the opening portion of the acoustic pipe 1 is constituted of the soft acoustic section 4 and, at the same time, the closed portion is constituted of the non-soft acoustic section 5, in the partition wall 11 (the acoustic pipe array for a partition wall 11), the acoustic pipe 1 which constitutes the soft acoustic section 4 on one boundary surface b constitutes the non-soft acoustic section 5 on another boundary surface b. Therefore, a thin partition wall 11 (the acoustic pipe array for a partition wall 11) can be formed along with the silencing function, and a noise which is propagated in the duct D can be silenced without lowering a exhaust performance from the duct D.

[0076] Further, since noises can be absorbed by adhering the sound absorbing member 3 on to the non-soft acoustic section 5, in addition to a frequency band which can be silenced by the soft acoustic section 4, other frequency band can also be silenced at the non-soft acoustic section 5, and the duct silencer A10 which has high silencing effect can be obtained.

[0077] Further, in the duct having a rectangular cross-sectional shape of the duct silencer, in view of a point that influences which are given to a noise propagation from two pairs of oppositely facing inner wall surfaces are independent with each other, a first silencing means is mounted on one pair of inner wall surfaces and, at the same time, a second silencing means which has silencing property different from silencing property of the first silencing means may be mounted on another pair of inner wall surfaces.

[0078] Furthermore, when a dimension of the opening width of the duct is longer than the wavelength of the sound wave to be silenced (hereinafter referred to as sound wave to be silenced), the duct is divided by partition walls so as to form a plurality of miniaturized ducts having a rectangular cross sectional shape

in the duct such that an opening width becomes a half wavelength or less of a sound wave to be silenced as so-called a cell-type or a splitter-type duct silencer, a first silencing means is mounted on one pair of inner wall surfaces out of two pairs of oppositely facing inner wall surfaces of the miniaturized ducts and, at the same time, a second silencing means which has silencing property different from silencing property of the first silencing means may be mounted on another pair of inner wall surfaces.

[0079] The above-mentioned silencing property suggests a frequency band which can be silenced by the respective silencing means and a damping of the sound wave which is then silenced. In this manner, by using two type of the silencing means which has different silencing property with each other, the sound wave of the different frequency band can be silenced by respective silencing means and the frequency band which can be silenced can be broadened. Particularly, as the first silencing means and the second silencing means, by combining two silencing means which has different silencing mechanism with each other, the more broadened frequency band can be silenced.

[0080] As this two type of the silencing means, a first silencing means which is constituted in a state that a soft acoustic section soft in acoustics where a sound pressure on an inner wall surface becomes substantially zero is formed over more than approximately a half wavelength of a sound wave to be silenced in the length direction of the duct and a second silencing means which is constituted in a state that sound absorbing portions for reducing the sound pressure of the sound wave to be silenced are formed on the inner wall surfaces can be combined. By adopting the above-mentioned constitution, the sound wave of the exclusive frequency band which constitutes the main component of the noise can be silenced by the first silencing means and, at the same time, the sound wave of the more broadened frequency band which is not silenced by the first

silencing means can be silenced by the second silencing means so as to effectively reduce the noise.

[0081] Here, the above-mentioned duct silencer can be mounted on the inside or on the outside of the duct, and when the duct silencer is attached on the inside of the duct, a new duct inner wall consisting of the soft acoustic section and a sound absorbing portion is formed at a position at which the new inner wall of the duct projects toward the central side of the duct than an original inner wall level of the duct, while in case the duct silencer is attached on the outside of the duct, a new duct inner wall consisting of the soft acoustic section and a sound absorbing portion is formed on the same level as the original inner wall of the duct.

[0082] The soft acoustic section which is formed by the first silencing means, to be more specific, may be constituted of the acoustic pipe (a 1/4 wavelength acoustic pipe) having a length thereof from the open end of the pipe disposed on the inner wall surface to the closed end set to 1/4 of a wavelength of a sound wave which becomes the object to be silenced. When the soft acoustic section is constituted of such an acoustic pipe, by changing a length of the acoustic pipe corresponding to a wavelength of a sound to be silenced, it is possible to silence sounds having various wavelengths.

[0083] Further, by mounting a film having a small resistance in acoustics and as an extremely large resistance as a fluid on the opening portion of the acoustic pipe, it is possible to constitute the soft acoustic section using acoustic pipes which are shorter than the above-mentioned 1/4 wavelength. Accordingly, by covering the opening portion of the acoustic pipe with a film made of plastic or the like, it is possible to easily realize the miniaturization of the duct silencer, the easy mounting of the duct silencer and the reduction of weight of the duct silencer. Further, in this manner, when the opening part is sealed by providing the film to the opening part

of the acoustic pipes, it is possible to reduce an air flowing sound caused by an air flowing thus broadening a noise reducing frequency band.

[0084] Further, besides forming the first silencing means by continuously providing the soft acoustic section soft in acoustics where the sound pressure on the inner wall surface becomes substantially zero as described above, it is also possible to form the first silencing means by alternately forming the soft acoustic section and the non-soft acoustic section where the sound pressure at the inner wall surface of the passage is not zero over more than approximately a half wavelength of a sound wave to be silenced in the length direction of the duct so as to become a checkered pattern or in a striped pattern. In this case, the region which is occupied by the soft acoustic section which is to be constituted such that the sound pressure thereof is zero can be reduced thus increasing a region of the duct on which the duct silencer can be mounted.

[0085] Particularly, the above-mentioned non-soft acoustic section can be a sound absorbing acoustic section which has a function of reducing a sound pressure, which is not zero, by using a sound absorbing member such as a metallic fiber represented by glass wool, rock-wool and aluminum fiber, a foamed aluminum, a ceramic absorbing material or the like, a rigid acoustic section rigid in acoustics which is made of a rigid body such as a metal plate in the same manner as a duct and has no sound pressure reducing function and the like. In the non-soft acoustic section, a silencing function (a noise reduction function) is not a prerequisite. For example, an original wall surface of the duct may be used as the non-soft acoustic section. Accordingly, by constituting the first silencing means such that the soft acoustic section and the non-soft acoustic section are alternately formed, in the inside of the duct, not to mention that the sound wave to be silenced can

be silenced by the silencing function of the soft acoustic section, by making use of the non-soft acoustic section which is alternately arranged with the soft acoustic section as either the sound absorbing acoustic section or the rigid acoustic section as mentioned previously, the duct silencer can be used for multi purposes.

[0086] Further, by assuming the above-mentioned non-soft acoustic section as a sound absorbing acoustic section and by forming the non-soft acoustic section using a sound absorbing member such as a fiber material which can decrease the sound pressure, it is possible not only to silence a sound wave in a predetermined frequency band which is an object sound wave in the soft acoustic section, but also to silence a sound wave in a different predetermined band in the non-acoustic section, the frequency band in which the sound wave can be silenced in the silencer can be expanded so as to enhance the silencing effect of the silencer.

[0087] On the other hand, as mentioned above, by forming the wall surface per se of the duct into the non-acoustic section, the new structure can be obviated whereby the silencer becomes light-weighted.

[0088] Further, also when the soft acoustic section is constituted of the acoustic pipe, the non-soft acoustic section is formed between the acoustic pipes which constitute the soft acoustic section and hence, even when the soft acoustic section is occupied with the acoustic pipes, the non-soft acoustic section may be provided as open spaces thus using these open spaces for other purposes. For example, when the non-soft acoustic section is provided as open spaces, it is possible to arrange a portion of the acoustic pipe at a position close to the non-soft acoustic section by bending the acoustic pipe at a midst portion thereof. In this case, it is possible to realize the miniaturization of the duct silencer compared with a case that the acoustic pipe extends straight. Accordingly, it is

possible to broaden the possibility that the duct silencer of the present invention can be installed.

[0089] Further, when the above-mentioned acoustic pipes are applied to the partition walls which divide the inside of the duct into a plurality of small ducts, it is possible to form the soft acoustic section by arranging the open end of the acoustic pipe on one wall surface of the partitions and to form the non-soft acoustic section by arranging the closed end of the acoustic pipe on another wall surface of the partitions. Due to such a constitution, it is sufficient that the thickness of the partition wall is set to a length of one acoustic pipe and hence, the partition wall may be formed thin. Accordingly, even when the duct is divided by the partition walls, an area where the partition walls occupies in cross section of the duct can be decreased as much as possible thus silencing the object sound wave without lowering an air fluidity in the inside of the duct.

[0090] On the other hand, a sound absorbing section which is formed of a second silencing means, to be more specific, may be constituted of a sound absorbing member such as a metallic fiber represented by glass wool, rock-wool and aluminum fiber, a foamed aluminum, a ceramic sound absorbing material or the like. Here, by forming the sound absorbing section using such a sound absorbing member, it is possible to silence the sound wave in a broad frequency band, to be more specific, in a high frequency band. Further, with the use of a non-fiber material such as the above-mentioned ceramic sound absorbing material as a material of the sound absorbing member, it is possible to overcome a drawback related to a scattering of a material which has been considered as a problem to be overcome conventionally.

[0091] Hereinafter, specific embodiments of the duct silencer are explained in conjunction with drawings.

[0092] Fig. 12 shows a first duct silencer A11 which constitutes one embodiment of the duct silencer.

[0093] The first duct silencer A11 is a duct silencer for an experiment which is designed to measure a silencing ability thereof. The first duct silencer A11 is constituted of a pair of left and right first acoustic pipe arrays 37 which constitutes first silencing means and a pair of upper and lower sound absorbing members 33 which constitutes second silencing means and is formed into a cylindrical shape with an inner space having a square cross sectional shape of 10 cm x 10 cm and a length of 50 cm.

[0094] The above-mentioned first acoustic pipe array 37 is constituted to set in array the plural acoustic pipes in a perpendicular direction and/or a horizontal direction, and is configured such that the acoustic pipes (a 1/4 wavelength acoustic pipe) 1 made of aluminum having a sectional shape of 5 cm by 5 cm and a length of 85mm which is 1/4 of the wavelength of 1000 Hz are arranged in parallel in 2 rows and 10 columns and is mounted in a state that a surface b (hereinafter, referred to as a boundary surface) which is boundary with a inner space of a duct D', that is, the inner wall surface of the duct D' becomes a opening portions of the first acoustic pipe 31.

[0095] Further, the sound absorbing member 33 is made of plate-like glass wool having a thickness of 50 mm and density of 32 kg/m^3 and forms a sound absorbing section 36 which extends toward an inner space of a duct D'. Furthermore, an outer peripheral portion of the sound absorbing member 33 which does not face the inner space of the duct D3 is covered with a casing 14 made of an acrylic plate having a thickness of 20 mm thus preventing leaking of noises to the outside of the duct D' from the inside of the duct D' and, at the same time, preventing the intrusion of noises to the inside of the duct D' from the outside of the duct D'.

[0096] Further, Fig. 13 shows a second duct silencer A12 which constitutes another embodiment.

[0097] The second duct silencer A12 is also a duct silencer for experiment which is designed on a premise that a silencing ability of the silencer A12 is measured and differs from the above-mentioned first duct silencer A11 only with respect to the constitution of the acoustic pipe array. That is, in the second duct silencer A12, among the acoustic pipes 31 of the first acoustic pipe array 37, opening portions of the acoustic pipes 31 of the above-mentioned first acoustic pipe array 37 are closed by a rigid body 32 such as an aluminum plate in a checkered pattern such that the neighboring acoustic pipes 31 do not open continuously and, at the same time, the second acoustic pipe array 38 which adheres glass wool constituting the sound absorbing member 33 to the rigid body.

[0098] In this manner, in both of the first duct silencer A11 and the second duct silencer A12, the acoustic pipe array is designed by setting the silencing object frequency to 1000 Hz, wherein the first acoustic pipe array 37 of the first duct silencer A11 has an all boundary surface b thereof formed into a soft acoustic section 34 over a half wave length of the silencing object frequency, while the second acoustic pipe array 38 of the second duct silencer A12 has a boundary surface b thereof formed into a checkered pattern made of the soft acoustic sections 34 and the non-soft acoustic section 35 over a half wave length of the silencing object frequency.

[0099] Here, in the above-mentioned first duct silencer A11 and the second duct silencer A12, the acoustic pipes 31 are made of aluminum and the sound absorbing members 33 are made of glass wool. However, the first duct silencer A11 and the second duct silencer A12 are provided exclusively as duct silencing devices for experiments. That is, the duct silencers are not limited to these materials and materials which can constitutes the soft acoustic section 34 and the sound absorbing section 36 can be properly used. Further, the shape of the acoustic pipe 31 is not limited to a rectangular cross section and the acoustic pipe

31 has any cross-sectional shape provided that the acoustic pipe 31 is formed in a cylindrical shape. Further, the constitution of the acoustic pipe array and the thickness of the sound absorbing member 33 may be also properly adjusted. Still further, in the second duct silencer A12, two opposing second acoustic pipe arrays 38 may also be configured such that the soft acoustic sections 34 face each other and the non-soft acoustic sections 35 face each other or may be constituted such that the soft acoustic section 34 and the non-soft acoustic section 35 face each other.

[0100] The above-mentioned first duct silencer AS11 and the second duct silencer A12 are compared with a duct silencer which is provided with only the first silencing means and a duct silencer which is provided with only the second silencing means with respect to the silencing ability.

[0101] Fig. 14 shows the boundary surface structure of the first duct silencer A11 and the boundary surface structures of a third duct silencer A13 and a fifth duct silencer A15 which constitute comparison examples of the first duct silencer A11. The third duct silencer A13 is constituted such that the first acoustic pipe array 37 which constitutes the first silencing means is provided to the portion where the sound absorbing member 33 which constitutes the second silencing means is provided in the first duct silencer A11 thus forming all 4 surfaces which face the inner space of the duct D' using only the first silencing means, while the fifth duct silencer A15 is constituted such that the sound absorbing member 33 which constitutes the second silencing means is provided to portions where the first acoustic pipe array 37 which constitutes the first silencing means in the above-mentioned first duct silencer A11 are provided thus forming all 4 surfaces which face the inner space of the duct D' using only the second silencing means.

[0102] Fig. 15 shows the boundary surface structure of the second duct silencer A12 and the boundary surface structures of

a fourth duct silencer A14 and a fifth duct silencer A15 which constitute comparison examples of the second duct silencer A12. The fourth duct silencer A14 is constituted such that the second acoustic pipe array 38 which constitutes the first silencing means is provided to the portion where the sound absorbing member 33 which constitutes the second silencing means is provided in the second duct silencer A12 thus forming all 4 surfaces which face the inner space of the duct D' using only the first silencing means, while the fifth duct silencer A15 is constituted such that the sound absorbing member 33 which constitutes the second silencing means is provided to portions where the second acoustic pipe array 38 which constitutes the first silencing means in the above-mentioned second duct silencer A12 are provided thus forming all 4 surfaces which face the inner space of the duct D' using only the second silencing means as explained in conjunction with Fig. 14.

[0103] Further, in Fig. 16, a measuring device M' which measured silencing capacities of the above-mentioned first to fifth duct silencers A11 to A15 is shown.

[0104] The measuring device M' includes an acrylic-resin-made duct D' which has a square cross-sectional shape of 10 cm x 10 cm and a length of 2 m. A terminal end portion of the duct end D' is formed into a non-reflective end on which a sound absorbing wedge M'1 is mounted, a speaker M'2 which constitutes a sound source is mounted on a start end portion of the duct D' opposite to the non-reflective end, and a microphone M'3 which collects the sound outputted from the speaker M'2 is mounted in front of the above-mentioned sound absorbing wedge M'1 which is arranged closer to the non-reflective end side than the speaker M'2.

[0105] Further, between the speaker M'2 and the microphone M'3, that is, on a center portion of the duct D' which is arranged closer to the non-reflective end side than the speaker M'2, the above-mentioned first to fifth duct silencers A11 to A15 to be

tested are mounted and hence, it may be measured how much a sound outputted from the M'2 is silenced by passing through the duct silencer. Here, a "closed triangle" shown in Fig. 14 and Fig. 15 indicates a direction to be a start end side (the side on which a speaker M2 is mounted) of the duct D at the time of mounting the duct silencer on the measuring device M'.

[0106] Fig. 17 shows a result of measurement of the silencing ability of the above-mentioned first duct silencer A11 and the silencing abilities of the third duct silencer A13 and the fifth duct silencer A15 which are comparison examples of the first duct silencer A11. Here, in Fig. 17, an axis of ordinates indicates sound volumes (dB) of sound waves which are collected when the respective duct silencers A11, A13 and A15 are mounted as an attenuation quantity (dB) from a reference value, wherein a volume (dB) of a sound wave which is collected by the microphone M'3 when the first duct silencer A11 is not mounted and all inner wall surfaces of the duct D' is formed of a rigid body 32 as the reference value. Further, an axis of abscissas indicates the frequency (Hz) of the sound wave collected by the microphone M'3 within a range from 315 Hz to 3000 Hz.

[0107] A solid line indicates, as shown in Fig. 14, a result of the measurement of the first duct silencer A11. The solid line implies that a large attenuation quantity of 40 dB or more is obtained in a frequency band from approximately 800 Hz to approximately 1800 Hz with 1000 Hz which is designed frequency of the 1/4 wave length acoustic pipe 31 as the center of the frequency band and a silencing effect is obtained in a relatively broad frequency band covering one octave.

[0108] On the other hand, a chained line indicates, as shown in Fig. 14, a result of the measurement of the third duct silencer A13 which is constituted only of the first acoustic pipe array 37. To compare the measurement result of the third duct silencer A13 and the measurement result of the first duct silencer A11, in all frequency bands, the above-mentioned first

duct silencer A11 can obtain the greater attenuation quantity. Particularly, on the high frequency banc side above 1600Hz, the difference of silencing effect is increased.

[0109] Further, a dotted line indicates, as shown in Fig. 14, a result of measurement of the fifth duct silencer A15 which is constituted of only the sound absorbing member 33. To compare the measurement result of the fifth duct silencer A15 with the measurement result of the first duct silencer A11, it is understood that the first duct silencer A11 can obtain the extremely large attenuation quantity within a range from 800 Hz to 1900 Hz in comparison with the above-mentioned first duct silencer A11.

[0110] In this manner, it is found that the first duct silencer A11 which arranges silencing means which are different in silencing characteristics from each other on two pairs of opposing inner wall surfaces of the duct D' having the rectangular cross section can obtain the high silencing effect within the broad frequency band compared with the third duct silencer A13 and the fifth duct silencer A15 which arrange the silencing means having the same silencing characteristics on two pair of opposing inner wall surfaces of the duct D'.

[0111] Fig. 18 shows a result of measurement of the silencing ability of the above-mentioned first duct silencer A12 and the silencing abilities of the third duct silencer A14 and the fifth duct silencer A15 which are comparison examples of the first duct silencer A12. Here, also in Fig. 18, in the same manner as Fig. 17, an axis of ordinates indicates sound volumes (dB) of sound waves which are collected when the respective duct silencers A12, A14 and A15 are mounted as a attenuation quantity (dB) from a reference value. Further, an axis of abscissas indicates the frequency (Hz) of the sound wave collected by the microphone M'3 within a range from 315 Hz to 3000 Hz.

[0112] A solid line indicates, as shown in Fig. 15, a result of the measurement of the first duct silencer A12. The solid line

implies that a large attenuation quantity of 40 dB or more is obtained in a frequency band from approximately 900 Hz to approximately 1600 Hz with 1000 Hz which is designed frequency of the 1/4 wave length acoustic pipe 31 as the center of the frequency band. Further, in the frequency band above approximately 800 Hz, the attenuation quantity of 30 dB or more is always obtained. To compare this result with the result of the first duct silencer A11, although the frequency band in which the attenuation quantity of 40 dB is slightly small, the silencer A12 can more stably obtain the attenuation quantity of 30 dB or more than the first duct silencer A11 in the high frequency band of 2000 Hz or more.

[0113] On the other hand, a chained line indicates, as shown in Fig. 15, a result of the measurement of the third duct silencer A14 which is constituted only of the second acoustic pipe array 38. To compare the measurement result of the third duct silencer A14 and the measurement result of the second duct silencer A12, in almost all frequency bands, the above-mentioned second duct silencer A12 can obtain the greater attenuation quantity.

[0114] Further, a dotted line indicates, as shown in Fig. 14, a result of measurement of the fifth duct silencer A15 which is constituted of only the sound absorbing member 33. To compare the fifth duct silencer A15 with the second duct silencer A12, in the same manner as the comparison with the first duct silencer A12, the second duct silencer A12 can obtain the more attenuation quantity over one octave with the designed frequency of the 1/4 wave length acoustic pipe 31 as the center of the frequency band.

[0115] In this manner, it is also found that the second duct silencer A12 which uses the second acoustic pipe array 38 in which the soft acoustic section 34 and the non-soft acoustic section 35 are arranged in a checkered pattern as the first silencing means can obtain the high silencing effect within the

broad frequency band compared to the fourth duct silencer A14 and the fifth duct silencer A15 which arrange silencing means having the same silencing characteristics on two pairs of opposing inner wall surfaces of the duct D' having the rectangular cross section.

[0116] Next, as another example, a case in which the duct silence is applied to a cell-type duct silencer is explained.

[0117] Fig. 19 is an explanatory view as viewed from a cross-section showing a state of an operation of a sixth duct silencer A16 of another embodiment, Fig. 20 is a cross-sectional explanatory view taken along a line III-III in Fig. 19, and Fig. 21 is an explanatory view showing an arrangement of the soft acoustic section 34 and the non-soft acoustic section 35 in a region II in Fig. 19.

[0118] As shown in the drawings, the sixth duct silencer A16 is mounted on an exhaust port D'1 portion of a duct D having a rectangular cross section which constitutes a cooling tower for air conditioning. The sixth duct silencer A16 is formed of acoustic pipe arrays for duct walls 39 which are arranged respectively on a pair of left and right facing inner wall surfaces of the duct D' as a first silencing means and acoustic pipe arrays for duct walls 41 which are arranged respectively on a pair of front and rear facing inner wall surfaces of the duct D' as a second silencing means, and is formed in a cylindrical shape having a rectangular cross-sectional view. Further, in the inside of the sixth duct silencer A16 Athree partition-wall-use acoustic pipe arrays 40 which become longitudinal partition walls which partition the duct D' in a longitudinal direction as a first silencing means and three partition-wall-use sound absorbing bodies 42 which become lateral partition walls which partition the duct D' in a lateral direction as a second silencing means are arranged. Accordingly, in the inside of the duct D', a plurality of miniaturized duct D'2 having a

rectangular cross-sectional view are formed. In the drawing, numeral 43 indicates a blower.

[0119] The above-mentioned acoustic pipe arrays for duct walls 39 are formed in a plate shape by arranging 1/4 wavelength acoustic pipes 31 made of aluminum having a rectangular cross-sectional shape with one closed end whereas another opened end in parallel along the duct wall in a perpendicular direction and a horizontal direction and, at the same time, the openings of the acoustic pipe 31 are alternately closed by rigid bodies 32 such as aluminum plates and sound absorbing members 33 made of glass wool are adhered on to the rigid bodies 32 in a state that the closed end or the opened end is not continuously arranged between two adjacent 1/4 wavelength acoustic pipes 31. As shown in Fig. 21, boundary surfaces b which is boundary with an inner space of a duct D', that is, surfaces to be inner wall surfaces of the duct D' are constituted of the openings (the soft acoustic section 34) of the acoustic pipes 31 and the sound absorbing members 33 (the non-soft acoustic section 35) which are adhered on to the rigid bodies 32 in a checkered pattern.

[0120] On the other hand, the acoustic pipe array for a partition wall 40 is formed in a plate shape by alternately arranging 1/4 wavelength acoustic pipes 31 made of aluminum having a rectangular cross-sectional shape with one closed end whereas another opened end in parallel in a perpendicular direction and a horizontal direction in a state that the closed end or the opened end is not continuously arranged between two adjacent 1/4 wavelength acoustic pipes 31, and in this embodiment, the acoustic pipe array for a partition wall 40 is constitutes a longitudinal partition wall as it is.

[0121] That is, the acoustic pipe array for a partition wall 40 is constituted in a state that front-back both surfaces constitute boundary surfaces b which is boundary with an inner space of a duct D', and the acoustic pipe 31 which the opening portion thereof is arranged on the one boundary surface b is

constituted in a state that the closed portion thereof is arranged on another boundary surface b. Further, the sound absorbing members 33 made of glass wool is adhered on to the above-mentioned closed portion, and in the boundary surface b, b of the front-back both sides of the acoustic pipe array for a partition wall 40, as shown in Fig. 21, the opening portion (the soft acoustic section 34) of the acoustic pipe 31 and the sound absorbing members 33 (the non-soft acoustic section 35) of the closed portion are formed in a checkered pattern.

[0122] Here, the above-mentioned acoustic pipe array for a duct wall 39 and acoustic pipe array for a partition wall 40 are arranged over the length of half wavelength or more of the sound wave to be silenced in a longitudinal direction of the duct D'.

[0123] Further, the duct-wall sound absorbing body 41 arranges the sound absorbing member 33 made of glass wool to face the inner space of the duct D' and, at the same time, has an outside thereof covered with a casing 44 made of an aluminum plate or the like.

[0124] On the other hand, the partition wall sound absorbing body 42 mounts the sound absorbing member 33 on both surfaces of a skeleton member 45 made of aluminum plate or the like thus forming sound absorbing sections 36 on both of front and back surfaces thereof, wherein the partition-wall sound absorbing body 42 per se forms a lateral partition wall directly. Due to the partition-wall sound absorbing body 42 which constitutes a lateral partition wall and the above-mentioned partition-wall acoustic pipe array 40 which constitutes the longitudinal partition wall, an opening width t of the duct D' is partitioned such that the opening width t becomes a half wave length or less of the object sound wave.

[0125] Also in the above-mentioned sixth duct silencer A16, first silencing means is arranged on one pair of opposing inner wall surfaces of the miniaturized duct D'2 having the rectangular cross section, and the sound silencing means are

arranged on another pair of opposing inner surfaces of the miniaturized duct D'2 and hence, it is possible to silence the noises which propagates in the inside of the duct D' over the broad band ranging from the low frequency band to the high frequency band. Particularly, in the duct silencer A16 according to this embodiment, since the opening portion of the acoustic pipe 31 is constituted of the soft acoustic section 34 and, at the same time, the closed portion is constituted of the non-soft acoustic section 35, in the vertical partition wall (the partition-wall-use acoustic pipe array 40), the acoustic pipe 31 which constitutes the soft acoustic section 34 on one boundary surface b constitutes the non-soft acoustic section 35 on another boundary surface b. Therefore, the thin vertical partition wall (the partition-wall-use acoustic pipe array 40) can be formed along with the silencing function, and a noise which is propagated in the duct D' can be silenced without lowering a exhaust performance from the duct D'.

[0126] Further, since noises can be absorbed by adhering the sound absorbing member 33 on to the non-soft acoustic section 35, in addition to a frequency band which can be silenced by the soft acoustic section 34, other frequency band can also be silenced at the non-soft acoustic section 35, and the duct silencer which has high silencing effect can be obtained. Here, the above-mentioned duct silencer is applicable to all ducts D' which are installed at sites which have to cope with noises such as an outdoor equipment of an air conditioning facility, a large-sided tunnel discharge device, a power generating apparatus besides the above-mentioned cooling tower for air conditioning.

[0127] Fig. 22 shows a result of experiment which confirms an advantageous effect when the thin film is mounted on the opening portion of the acoustic pipe.

[0128] In Fig. 22, a broken line (indicated by A17 in the drawing) indicates a result of measurement when glass wool

(thickness: 50mm, density: 32 kg/m^3) is laminated to one pair of opposing inner wall surfaces of a duct having a rectangular cross section and the acoustic types are mounted on another pair of inner wall surfaces of the duct thus forming the soft acoustic section, a dotted line (indicated by A18 in the drawing) indicates a result of measurement when glass wool (thickness: 25 mm, density: 64 kg/m^3) is laminated also to the above-mentioned soft acoustic section, a bold solid line (indicated by A19 in the drawing) indicates a result of measurement when a thin film (thickness: 50 (m) is laminated to the opening portion of the acoustic pipe of the duct with A17 indicated by the above-mentioned broken line with no tension, and a fine solid line (indicated by A20 in the drawing) indicates a result of measurement when a thin film (thickness: 50 (m) is laminated to the opening portion of the acoustic pipe of the duct with A18 indicated by the above-mentioned dotted line with no tension.

[0129] In Fig. 22, to compare A17 and A19 or A18 and A20, in both cases, it is confirmed that by laminating the thin film to the acoustic pipe, the frequency having the high silencing effect is shifted to the low frequency side and, at the same time, the silencing effect can be obtained also in the high frequency band.

[0130] In this manner, the frequency having the high silencing effect is shifted to the low frequency side by laminating the thin film to the opening portion of the acoustic pipe and hence, it is understood that by mounting the film on the opening portion of the acoustic pipe, it is possible to obtain the desired silencing effect by using the acoustic pipe whose length from the opening end to the closed end is shorter than 1/4 of the wave length of a sound wave which becomes an object to be silenced. That is, when the wave lengths of the sound waves which become objects to be silenced are equal, by mounting the film on the opening portion of the acoustic pipe, the length of

the acoustic pipe can be shortened thus realizing the miniaturization and the reduction of the silencer.

[0131] Further, it is possible to obtain the silencing effect also in the high frequency band by laminating the thin film to the opening portion of the acoustic pipe and hence, it is understood that the frequency band which exhibits the silencing effect of the silencer can be increased by providing the film to the opening portion of the acoustic pipe.

INDUSTRIAL APPLICABILITY

[0132] According to the present invention, on an inner wall surface of a duct, a soft acoustic section soft in acoustics where the sound pressure at the inner wall surface of the duct is approximately zero and a non-soft acoustic section where the sound pressure at the inner wall surface of the duct is not zero are alternately arranged over more than approximately a half wavelength of a sound wave to be silenced in the length direction of the passage and hence, it is possible to reduce the region which is occupied by the soft acoustic section which is required to have the particular constitution with the sound pressure of zero thus enhancing the region in the duct where the duct silencer can be mounted is increased.

[0133] Further, the duct is divided by partition walls such that an opening width becomes a half wave length or less of a sound wave which becomes an object to be silenced, and on both side surfaces of the partition wall, a soft acoustic section soft in acoustics where the sound pressure at the inner wall surface of the duct is approximately zero and a non-soft acoustic section where the sound pressure at the inner wall surface of the passage is not zero are alternately arranged over more than approximately a half wavelength of a sound wave to be silenced in the length direction of the duct and hence, a region which is occupied by the soft acoustic section which is to be constituted such that a sound pressure thereof is zero can be

reduced, whereby a region which is capable of mounting a duct silencer in the partition wall can be increased.

[0134] Further, the soft acoustic section is formed of an acoustic pipe having a length thereof from an open end of the pipe disposed on a wall surface to a closed end set to 1/4 of a wavelength of a sound wave which becomes the object to be silenced and hence, it is possible to silence sounds of various wave lengths by changing the length of the acoustic pipe corresponding to the wave length of the sound to be silenced. Particularly, the non-soft acoustic section is provided between the acoustic pipe and the acoustic pipe which constitutes the soft acoustic section and hence, even when the soft acoustic section is occupied with the acoustic pipe, it is unnecessary to arrange the acoustic pipe in the above-mentioned non-soft acoustic section whereby the vacant space can be utilized for other purposes.

[0135] Further, the soft acoustic section is formed by arranging open end of the acoustic pipe on one wall surface of the partition wall, and the non-soft acoustic section is formed by arranging a closed end of the acoustic pipe on another wall surface and hence, it can be sufficient that the thickness of the partition wall is set to a length of one acoustic pipe, whereby the partition wall may be formed thin. Accordingly, even when the duct is divided by the partition walls, an area where the partition walls occupies in cross section of the duct can be decreased as much as possible and hence, the duct can be used effectively.

[0136] Further, the non-soft acoustic section is formed of a sound absorbing member which reduces a sound pressure and hence, it is possible to silence a sound wave in a predetermined frequency band in the soft acoustic section and, at the same time, it is possible to silence a sound wave in a different predetermined band in the non-acoustic section. Accordingly, the frequency band in which the sound wave can be silenced in

the silencer can be expanded thus enhancing the silencing effect of the silencer.

[0137] Further, the first silencer means is mounted on one pair of inner wall surfaces out of two pairs of oppositely facing inner wall surfaces of a duct having a rectangular cross section, the second silencing means which has silencing property different from silencing property of the first silencing means is mounted on another pair of inner wall surfaces and hence, the sound waves in the difference frequency bands can be silenced by the first silencer means and the second silencing means thus broadening the frequency band which can be silenced.

[0138] Further, the first silencing means forms the soft acoustic section soft in acoustics where the sound pressure at the inner wall surface of the duct is approximately zero over more than approximately a half wavelength or more of a sound wave to be silenced in the length direction of the duct and the second silencing means forms the sound absorbing section which reduces the sound pressure of the sound wave to be silenced on the inner wall surface and hence, the sound wave of the exclusive frequency band which constitutes the main component of the noise can be silenced by the first silencing means and, at the same time, the sound wave of the more broadened frequency band which is not silenced by the first silencing means can be silenced by the second silencing means so as to effectively reduce the noise.

[0139] Further, the first silencing means is configured such that the soft acoustic section soft in acoustics where a sound pressure on an inner wall surface becomes substantially zero and the non-soft acoustic section where the sound pressure at the inner wall surface of the duct is not zero are alternately arranged over more than approximately a half wavelength of a sound wave to be silenced in the length direction of the duct and the second silencing means forms the sound absorbing section which reduces the sound pressure of the sound wave to be

silenced on the inner wall surface and hence, the sound wave of the exclusive frequency band which constitutes the main component of the noise can be silenced by the first silencing means and, at the same time, the sound wave of the more broadened frequency band which is not silenced by the first silencing means can be silenced by the second silencing means so as to effectively reduce the noise. To be more specific, in the first silencing means, the region which is occupied by the soft acoustic section which is to be constituted such that the sound pressure thereof is zero can be reduced, whereby a region of the duct on which the duct silencer of the present invention is increased.

[0140] Further, the soft acoustic section is formed of an acoustic pipe having a length thereof from an open end of the pipe disposed on the inner wall surface to a closed end set to 1/4 of a wavelength of a sound wave which becomes the object to be silenced and hence, it is possible to silence sounds of various wave lengths by changing the length of the acoustic pipe corresponding to the wave length of the sound to be silenced.

[0141] Further, the duct is divided by partition walls so as to form a plurality of miniaturized ducts having a rectangular cross section in the duct such that an open width becomes a half wavelength or less of a sound wave which becomes an object to be silenced, a first silencing means is mounted on one pair of inner wall surfaces out of two pairs of oppositely facing inner wall surfaces of the miniaturized duct, a second silencing means which has silencing property different from silencing property of the first silencing means is mounted on another pair of inner wall surfaces and hence, the sound waves in the difference frequency bands can be silenced by the first silencer means and the second silencing means thus broadening the frequency band which can be silenced.

[0142] Further, the first silencing means forms the soft acoustic section soft in acoustics where the sound pressure at

the inner wall surface of the duct is approximately zero over more than approximately a half wavelength or more of a sound wave to be silenced in the length direction of the duct and the second silencing means forms the sound absorbing section which reduces the sound pressure of the sound wave to be silenced on the inner wall surface and hence, the sound wave of the exclusive frequency band which constitutes the main component of the noise can be silenced by the first silencing means and, at the same time, the sound wave of the more broadened frequency band which is not silenced by the first silencing means can be silenced by the second silencing means so as to effectively reduce the noise.

[0143] Further, the first silencing means is configured such that the soft acoustic section soft in acoustics where a sound pressure on an inner wall surface becomes substantially zero and the non-soft acoustic section where the sound pressure at the inner wall surface of the duct is not zero are alternately arranged over more than approximately a half wavelength of a sound wave to be silenced in the length direction of the duct and the second silencing means forms the sound absorbing section which reduces the sound pressure of the sound wave to be silenced on the inner wall surface and hence, the sound wave of the exclusive frequency band which constitutes the main component of the noise can be silenced by the first silencing means and, at the same time, the sound wave of the more broadened frequency band which is not silenced by the first silencing means can be silenced by the second silencing means so as to effectively reduce the noise. To be more specific, in the first silencing means, the region which is occupied by the soft acoustic section which is to be constituted such that the sound pressure thereof is zero can be reduced thus increasing a region of the duct on which the duct silencer can be mounted.

[0144] Further, the soft acoustic section is formed of an acoustic pipe having a length thereof from an open end of the

pipe disposed on the inner wall surface to a closed end set to 1/4 of a wavelength of a sound wave which becomes the object to be silenced and hence, it is possible to silence sounds of various wave lengths by changing the length of the acoustic pipe corresponding to the wave length of the sound to be silenced.

[0145] Further, the soft acoustic section is formed by arranging open end of the acoustic pipe on one wall surface of the partition wall, and the non-soft acoustic section is formed by arranging a closed end of the acoustic pipe on another wall surface and hence, it can be sufficient that the thickness of the partition wall is set to a length of one acoustic pipe, whereby the partition wall may be formed thin. Accordingly, even when the duct is divided by the partition walls, an area where the partition walls occupies in cross section of the duct can be decreased as much as possible and hence, the duct can be used effectively.

[0146] Further, when the films are formed on the open end of the acoustic pipes, it is possible to realize the miniaturization and the reduction of weight of the silencer and, at the same time, it is possible to silence the sound wave in a further wide frequency band.